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HIGH TEMPERATURE SLOW CRACK GROWTH IN SILICON CARBIDE.(U)
MAR 77 D E SCHWAB, H A WARREN N00014-76-C-0249
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AIRESEARCH MANUFACTURING COMPANY
OF CALIFORNIA

ANNUAL SUMMARY REPORT

HIGH TEMPERATURE SLOW CRACK GROWTH IN SILICON CARBIDE
(13 Oct 1975-13 Oct 1976)

77-13571 March 30, 1977

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~~Prepared by~~

(10) D. E. Schwab (David)
Materials Engineering
and
Harry A. Warren
~~Applied Mechanics~~

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Approved: W. S. Miller
W. S. Miller
Program Manager

Approved: Jim O'Reilly
J. O'Reilly
Chief Engineer
Heat Transfer and Cryogenic Systems

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ABSTRACT

Double-torsion crack growth tests of Super KT siliconized Silicon carbide were conducted from 871 to 1316 C in air, under static and cyclic loading. No slow static-crack growth was observed. Cyclic-slow crack growth of 0.03 to 0.20 μm/cycle was observed at ΔK values of 1.95 to 4.31 $MNm^{-3/2}$. The range of K_{IC} values was 2.45 to 5.53 $MNm^{-3/2}$. It was concluded that more definitive testing is needed to characterize the material's response to cyclic and static loads.

ACKNOWLEDGEMENTS

This report was prepared by David E. Schwab of the Materials Engineering Department, the Principal Investigator and Harry A. Warren of the Engineering Sciences Department. Dr. Ting Y. Liu of the Engineering Sciences Department was Co-Principal Investigator in charge of data analysis and application. William S. Miller of the Heat Transfer and Cryogenic Systems Department served as Program Manager. The high-temperature testing was conducted at California State University, Long Beach, under the supervision of Dr. C. Barclay Gilpin. The assistance of Dr. A. G. Evans, D. W. Richerson, D. W. Roy and T. M. Yonushonis is most gratefully acknowledged.

Mr. M. Keith Ellingsworth of the Power Program, Material Sciences Division, Office of Naval Research, was the Technical Monitor on the program. His guidance and support have been deeply appreciated.

NOMENCLATURE

DT	Double-torsion (test)
hp	horsepower
K	Stress intensity factor
ΔK	Stress intensity range during cyclic loading
K_{Ic}	Fracture toughness (or critical stress intensity factor)
K_{mean}	Average stress intensity factor during cycling loading
KT	Trade name (Carborundum Co.)
NC-430	Trade name (Norton Co.)
NC-435	Trade name (Norton Co.)
P	Load
SiC	Silicon carbide
Siliconized	Densified by reaction of SiC and carbon with infiltrated silicon metal.
SKT	Trade name (Carborundum Co.)
V	Crack velocity or growth rate

CONTENTS

SECTION 1

INTRODUCTION

Currently, heat exchangers for use in gas turbine power systems are fabricated from iron-base alloys and are limited to heating the working fluid to 750°C. It is anticipated that future development of metallics can raise this temperature to the 800°C to 875°C range. However, it is unlikely that iron or nickel alloys can be used successfully when this temperature climbs to the 1000°C to 1200°C range, where significant performance gains are anticipated. The magnitude of performance gains possible is best illustrated by an example. A 40-hp closed-Brayton-cycle engine recently delivered to the Navy has growth potential to approximately 500 hp. This growth is accomplished by increases in both turbine inlet temperature and operating pressure, with no corresponding increase in size. In order to obtain the required increase in heat exchanger temperature capability, new materials and/or designs are required.

Ceramic materials such as silicon carbide are most attractive for this heat exchanger application because they possess high compressive yield strength, high resistance to creep in the temperature range of interest and are corrosion and oxidation resistant. Perhaps most important, they will provide the overall power system with significant cost and weight advantages over current systems.

Silicon carbide (SiC) has been selected as a material having good potential for high-temperature heat exchanger applications. At the temperatures where ceramic materials must operate in advanced engines, some strength degradation will occur. Therefore, it is important to characterize the strength properties in the elevated temperature regime to establish effective operational stress levels for heat exchanger component design. Thus, the primary objective of this program is the evaluation of safe working stresses for the application of silicon carbide material to heat exchangers.

Failure of most ceramic materials with the potential for high-temperature structural application is controlled by the propagation of small preexisting flaws until fracture occurs. The primary determinant of safe working stress and service life is the nature of slow crack growth in these materials.

The design of ceramic heat exchangers has been hindered due to the lack of reliable test methods for obtaining high-temperature material characteristics. Recently, however, a promising method for studying the high-temperature slow crack growth in ceramic material has been developed (1)*. This technique uses an essentially constant stress intensity specimen (the double torsion specimen) under constant displacement rate conditions.

*See list of references, Section 4.

In this program, slow crack growth characterization of SiC is being performed using a fracture mechanics approach, which enables the crack growth rate to be related to the stress intensity factor. From the measured flaw growth rate data, typical proof stress diagrams will be constructed for use in establishing safe working stress levels in ceramic heat exchangers, and a simple application study will be performed.

This report summarizes the progress during the first year of this program under Contract N00014-76-C-0249 with the Office of Naval Research.

SECTION 2

TECHNICAL PROGRESS SUMMARY

2.1 MATERIALS

Several grades of silicon carbide were considered for this program. Selection was first restricted to the siliconized grades (Norton Company's NC-430 and NC-435, and Carborundum Company's KT and Super KT) because their strength at 1200°C, fabricability, availability and combination of physical and oxidation resistant properties made them the leading class of ceramic heat exchanger materials. Of these, Super KT was the highest-strength material available; hence, it was chosen. (NC-430 and KT grades have been subsequently tested in a parallel program for the Electric Power Research Institute by the same team of investigators using identical test procedures (2).)

The initial group of specimens was found, by radiographic inspection, to contain both discrete and widely-distributed indications of high-density defects. The Carborundum Company determined that these specimens were not representative of future production material for heat exchangers and provided a second group of specimens, designated SKT-B, which exhibited a far more uniform radiographic structure. The SKT-B specimens were used to determine slow-crack growth and fracture behavior.

Figures 2-1 and 2-2 show some of the radiographs of the initial group and Figure 2-3 shows some of the radiographs of the second group of 25x75 mm specimens. (The light band in the center of each specimen is the side groove used to guide the growing crack).

Properties reported by the supplier, Carborundum, are listed in Table 2-1.

2.2 TEST PROCEDURE

2.2.1 Specimen Preparation

After inspection, a narrow groove, approximately 0.3 mm wide, was cut in one face of each double-torsion (DT) specimen, halfway through the 2 mm thickness. An edge notch was cut in one end of the specimen to a length of approximately 15 mm on the smooth face and 8 mm on the notched face. All grooving and notching was done with a diamond slitting saw blade 75 mm in diameter and 0.3 mm thick, using soluble oil coolant.

Each specimen was then solvent-cleaned and placed in a double-torsion test fixture, as shown in Figure 2-4, for precracking in an Instron** tester. A drop of water was placed in the groove after inverting the fixture/specimen assembly (to retain the water), and loading was applied so as to compress the assembly at a rate of 5 μm/min. As verified by acoustic emission measurements, a sudden drop in load signalled the formation of a precrack. A typical

*Uresco, Inc.
**Instron Corp.

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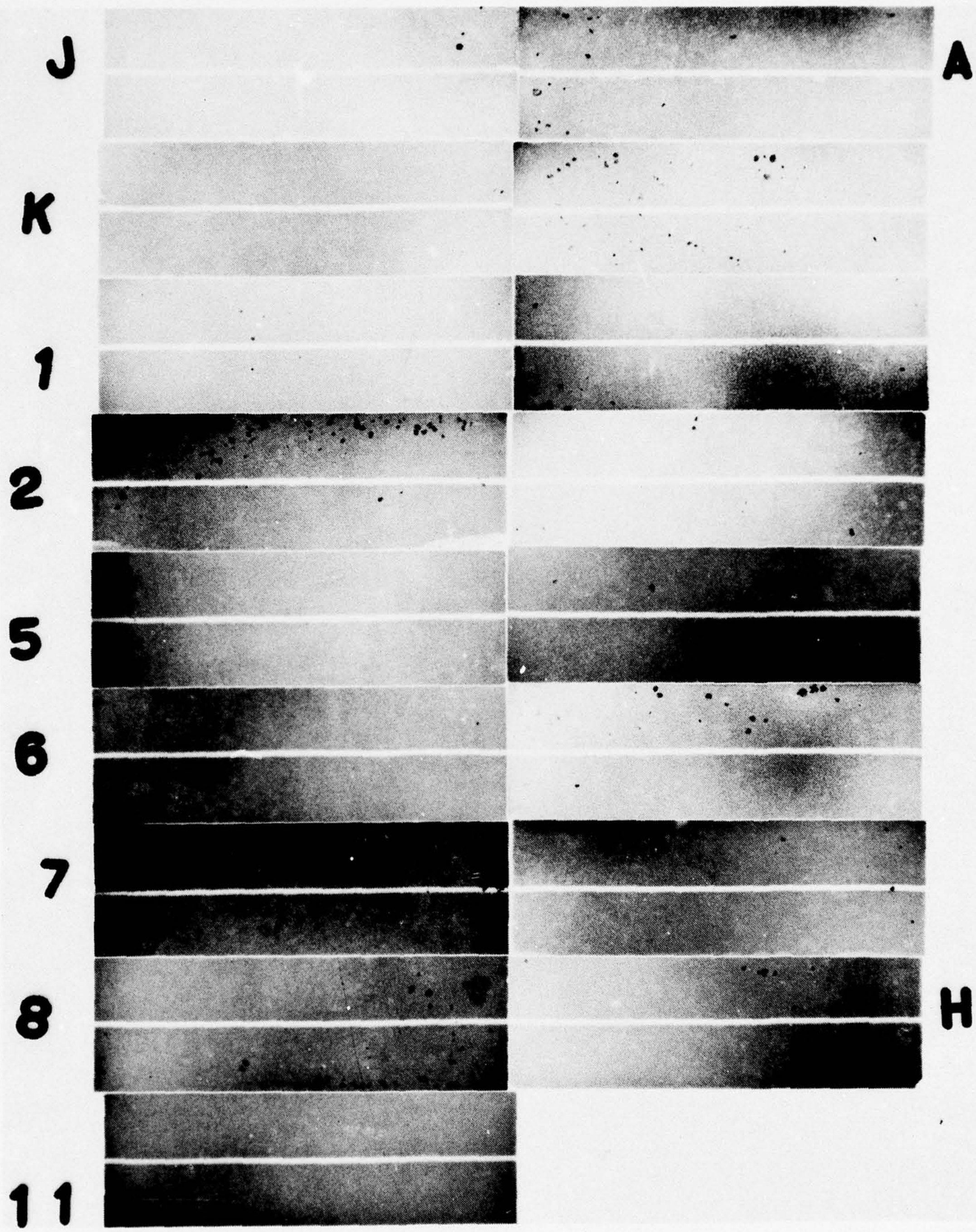

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Figure 2-1. Radiographs of Specimens No. A through K and 1 through 11 of Initial Batch (SKT-A)

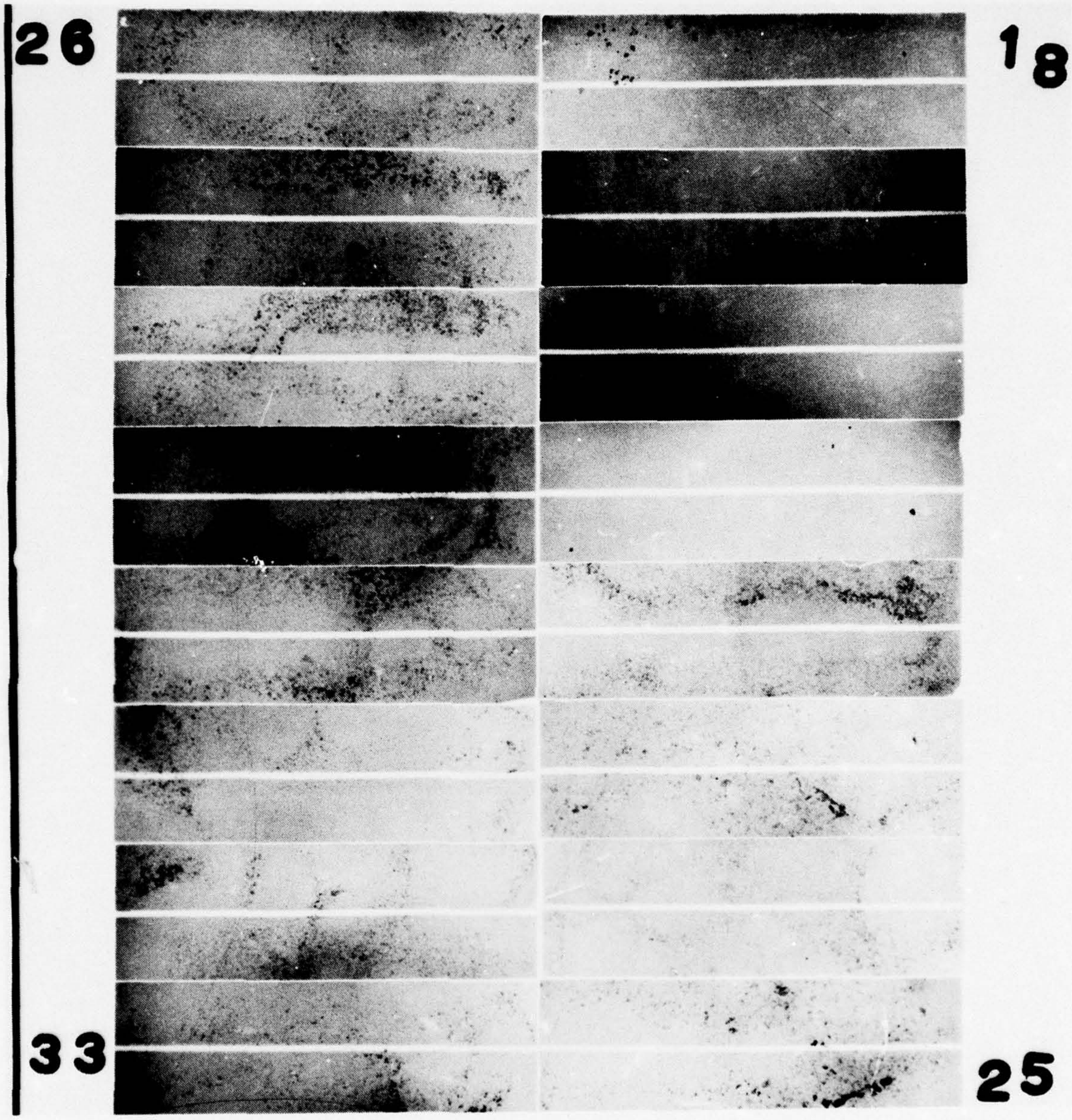

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Figure 2-2. Radiographs of Specimens 18 through 33 of Initial Batch (SKT-A)

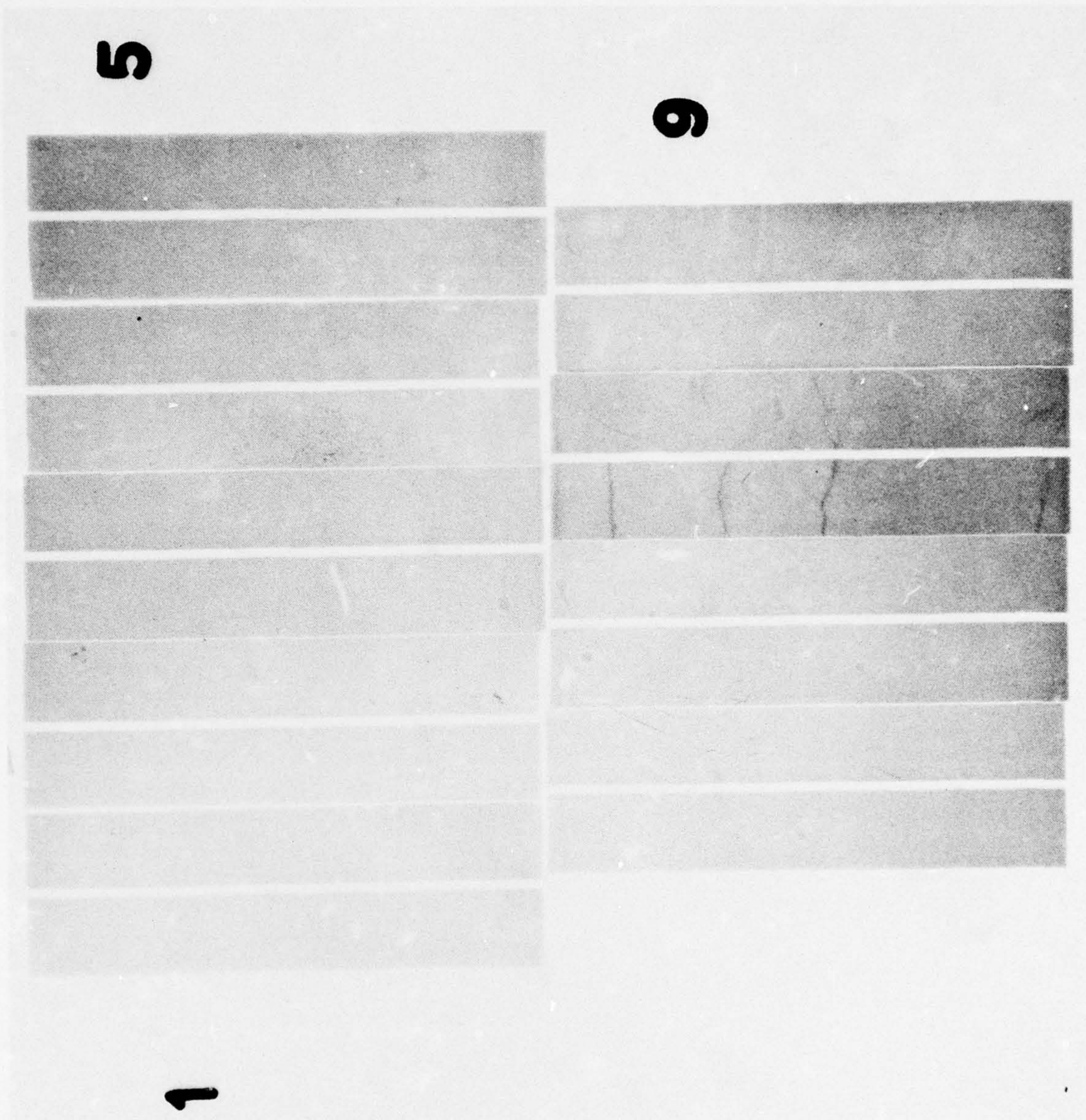

Figure 2-3. Radiographs of Specimens No. 1 through 9 of Second Batch (SKT-B) F-25353

TABLE 2-1

PROPERTIES OF SUPER KT TEST MATERIAL
BATCH NO. C-740-86

Hardness (Knoop)	2500
Chemistry (wt %)	8-12 Si(free), 0.200 Fe, 0.010 Ti, 0.050 Mn, 0.004 Ni, 0.200 Al, 0.010 Cu, 0.010 Ca, 0.004 V, 0.020 Cr, 0.006 B
Density (gm/cc)	3.1
Youngs Mod. 10^6 psi (GPa)	48 (330)
Torsional Mod.	22 (150)
Poisson's Ratio	0.11
Th. Exp. Coef.	
20-1400°C (10^{-6}/°C)	5.8
Thermal Cond. (cal/cm sec °C)	
25°C	0.22
600°C	0.08
Strength-Ksi (MPa)-4 pt	
R.T.	60 (410)
1200°C	55 (380)
1400°C	20 (140)
Weibull Mod. (2 parameter)	8-14

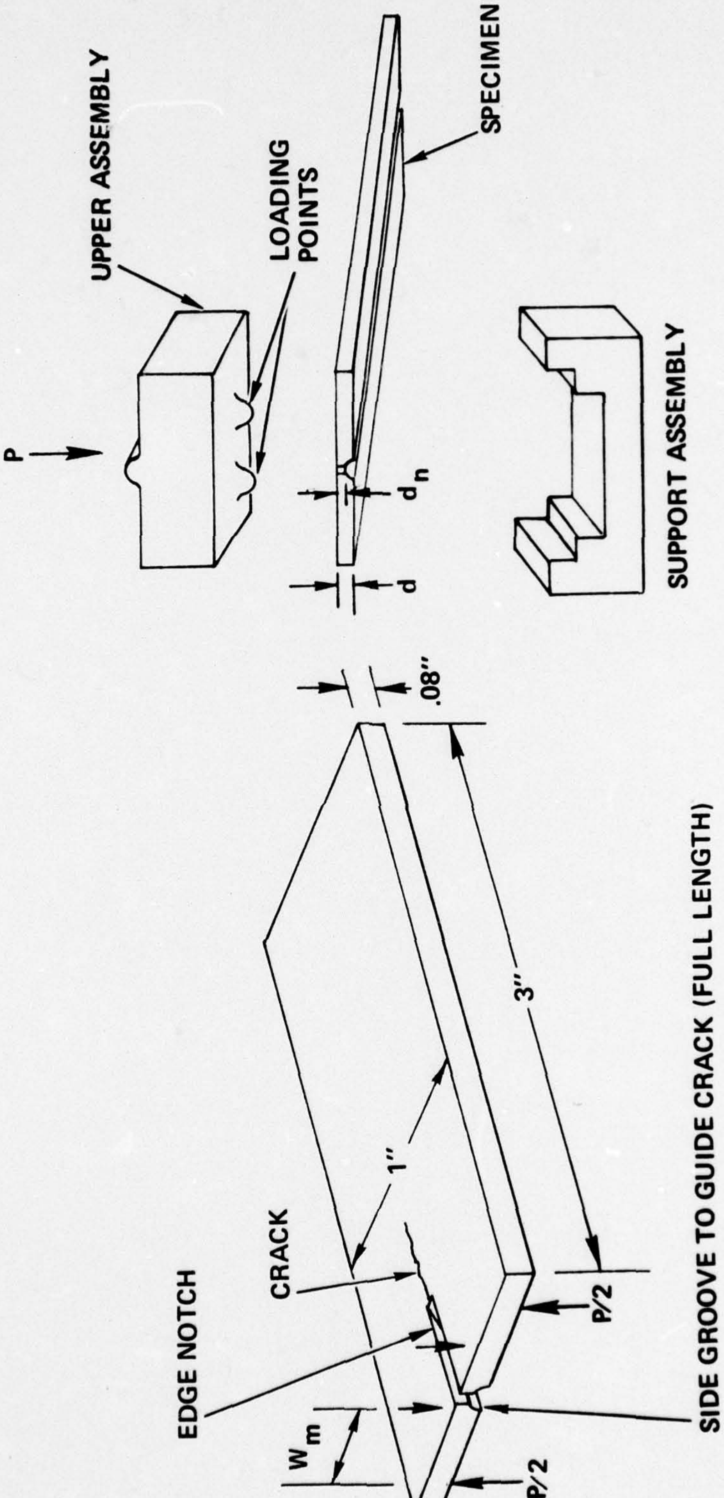

Figure 2-4. DOUBLE TORSION CRACK PROPAGATION TEST

S-14520

load-deflection plot taken during precracking is shown in Figure 2-5. The length of the crack was measured with P-136 water-washable flourescent dye penetrant. Figure 2-6 shows how clearly the crack could be viewed and measured. Using a microscope, the crack length could be readily measured to the nearest 1/4 mm.

2.2.2 High-Temperature Testing

Tests were conducted in an MTS* closed-loop servohydraulic test machine, using SiC push rods to apply load to the self-aligning SiC DT fixture containing the DT specimen. As shown in Figure 2-7, the fixture was enclosed in a 1371°C air furnace using SiC resistance heating elements. Temperature of the specimen was constant within ±3°C during loading.

Depending upon the test being conducted, either the deflection rate or load was maintained at a constant level (for static tests) or the load was cycled between specified limits (for dynamic tests). Constant displacement rate tests were conducted at 1.8 μm/min. Cyclic tests were conducted at 0.4 to 0.8 of the expected K_{Ic} value, which produced ΔK values in the range of 1.95 to 4.31 $MNm^{-3/2}$. Load, deflection rate and deflection were recorded on an autographic X-Y plotter as a function of time. Crack length was measured after testing, for computation of crack growth, to supplement recorded data, in those cases where the specimen remained intact after testing.

2.2.3 Test Matrix

The material property testing conducted on the program during this year is summarized in Table 2-2. The constant deflection rate tests did not produce useable crack growth data on the Super KT material. Three additional constant load rate tests, not shown in Table 2-2, were performed on glass specimens to see if the test method used on Super KT could duplicate published data when used on glass specimens.

2.3 RESULTS

2.3.1 Stress Intensity Tests

The data for determining the K_{Ic} values were obtained in two media. Room temperature K_{Ic} data was obtained in water during the precracking operation. Elevated temperature K_{Ic} data was obtained during the constant deflection rate tests in air. The K_{Ic} data are summarized in Figure 2-8.

The test fixture used in these tests utilized flat faced load application points rather than rounded points. When the specimen deflects under load, the load application point shifts from the centerline of the loading point to the edge. The K_{Ic} values in Figure 2-8 are based on the edge-to-edge moment arm (W_M = 0.25 in.). The values of K_{Ic} are presented in tabular form in Table 2-3.

Typical load vs deflection plots for room temperature and elevated temperature tests are shown in Figures 2-5 and 2-9. In these figures a sudden drop in load with a constant deflection indicates the formation of a crack in the specimen or the extensions of a preexisting crack.

*MTS Systems Corp.

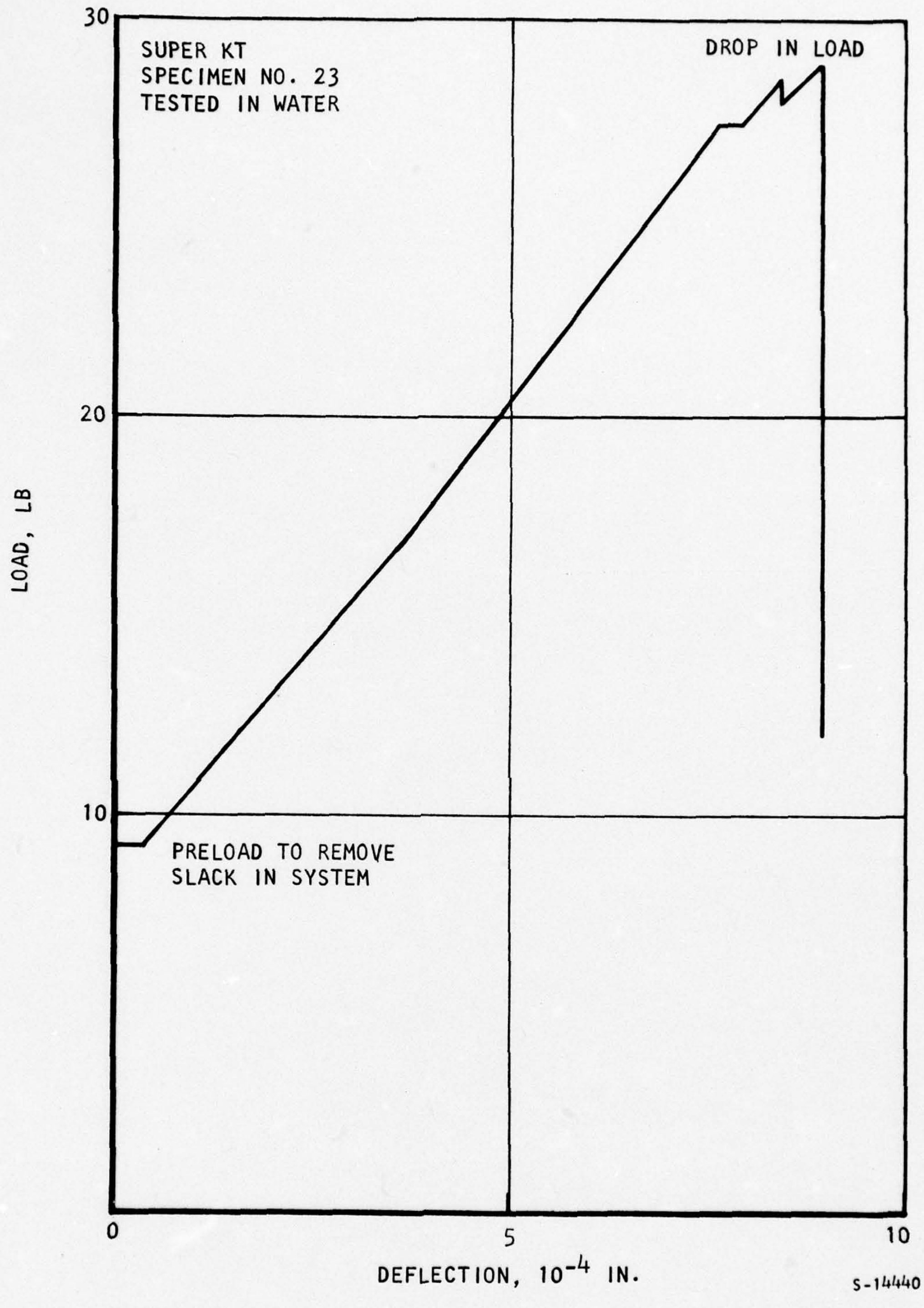

Figure 2-5. Typical Precrack Data

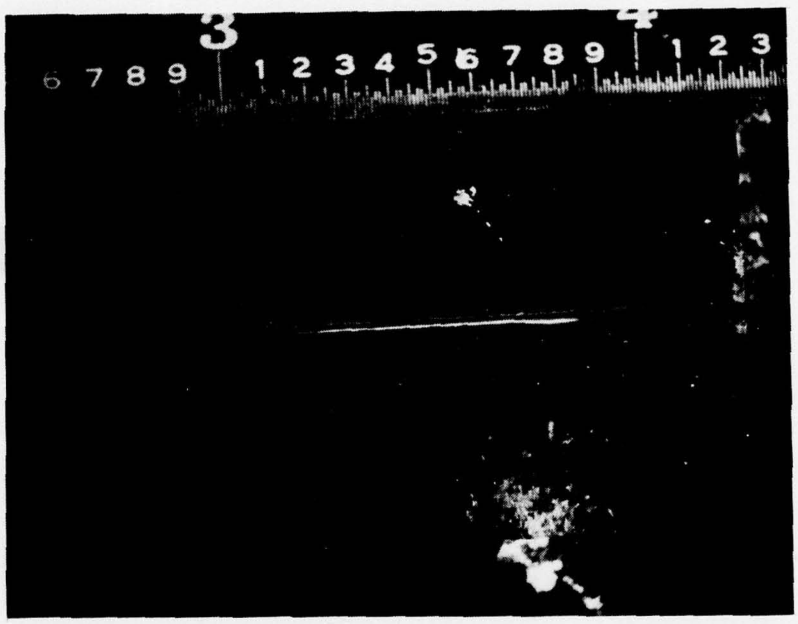

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Figure 2-6. Black-light Photomacrograph of Fluorescent Dye-Penetrant in Precrack. (Edge Notch is located at right-hand end of specimen.) The scale in the photo contains fine divisions 0.01 in. apart.

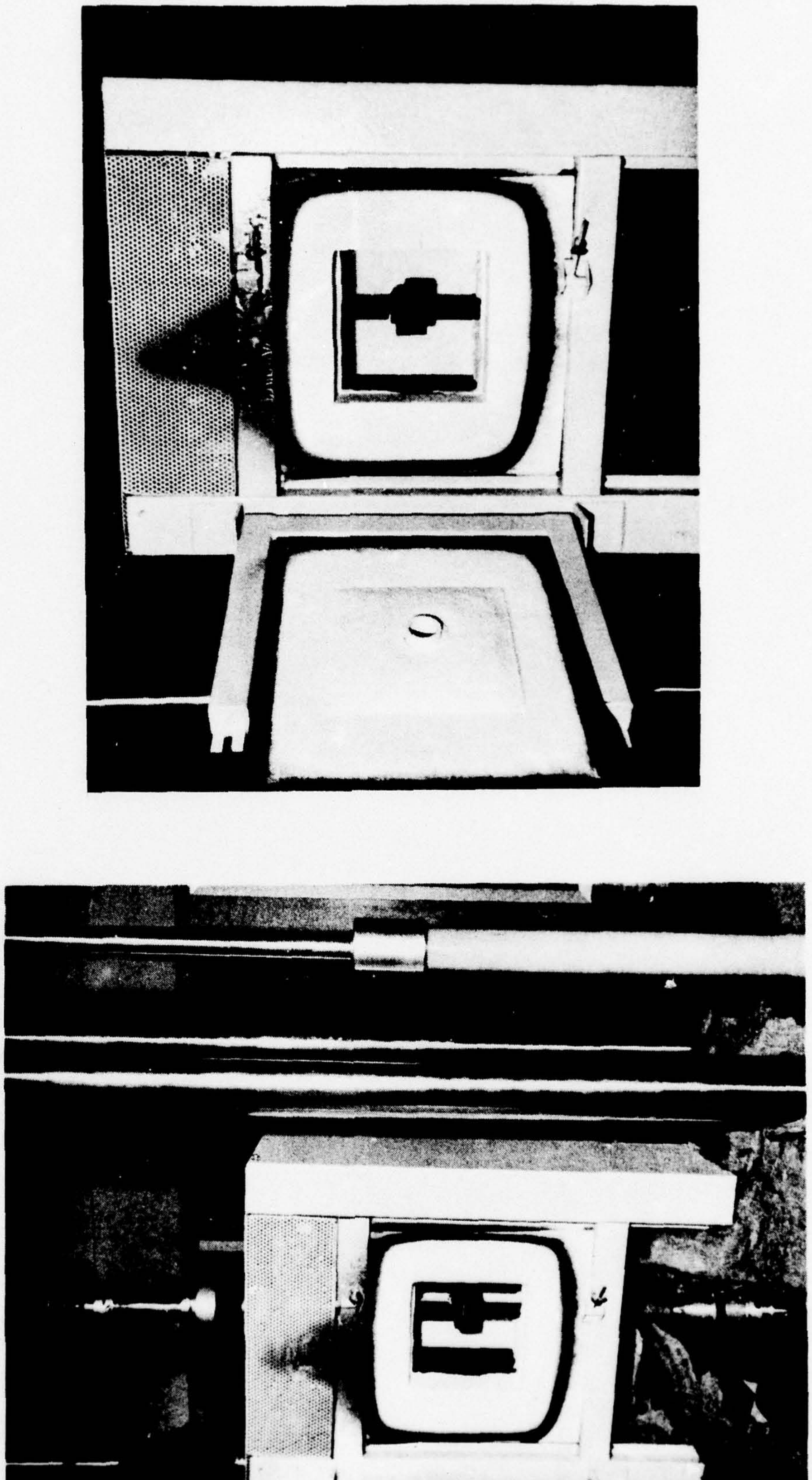

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Figure 2-7. High Temperature Furnace and Fixture

TABLE 2-2

SUMMARY OF TESTING

Number of Specimens Tested or
(Number of Data Points)*
For Each Test

Test Series	Temperature, °C			
	21	871	1093	1316
Stress Intensity Tests	17	2 (6)*	2	3
Slow Crack Growth, da/dt Constant Deflection Rate Tests	-	4	4	6
Slow Crack Growth, da/dt Constant Load Tests	-	-	-	1
Cyclic Crack Growth da/dt	-	2	2	7

*Up to three crack initiation points were obtained from each test specimen at elevated temperatures during the constant deflection rate testing. See Figure 2-10 for a typical plot of constant load rate data.

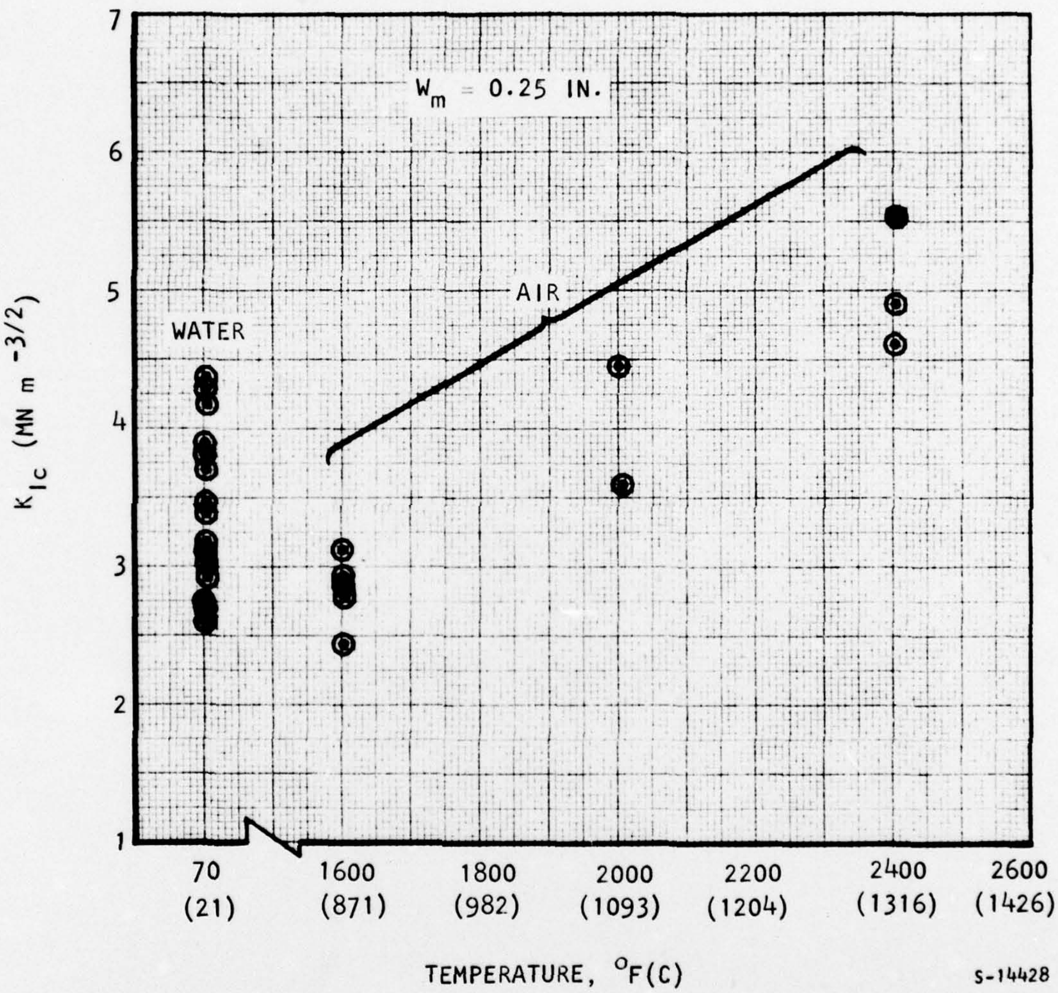

Figure 2-8. K_{Ic} for Super KT

TABLE 2-3

K_{Ic} DATA FOR SUPER KT SPECIMENS

Specimen No.	Ligament d_n (in.)	T_1* (^oC)	Load to Crack (lbs)	K_{Ic} at T_1 ($MNm^{-3/2}$)	T_2* (^oC)	Load to Crack (lbs)	K_{Ic} at T_2 ($MNm^{-3/2}$)
19	0.040	1316	42.5	4.90	21.	27.0	3.11
20	0.040				21	23.7	2.71
21	0.040	1316	48.0	5.53	21	30.0	3.46
22	0.041				21.	37.5	4.27
23	0.042	1316	40.0	4.61	21	28.7	3.37
25	0.043	1093	32.0	3.60	21	33.0	3.71
26	0.041	1093	39.0	4.44	21	27.7	3.15
27	0.043	871	22.0	2.45	21	27.0	3.00
		871	25.0	2.78			
		871	25.0	2.78			
28	0.043				21	39.5	4.39
29	0.043				21	34.9	3.88
30	0.044	871	26.0	2.86	21	26.6	2.92
		871	26.5	2.91			
		871	28.5	3.13			
31	0.043				21	34.5	3.84
32	0.043				21	27.0	3.00
33	0.043				21	23.4	2.60
34	0.041				21	34.0	3.87
35	0.041				21	36.7	4.18
36	0.041				21	23.7	2.70

*T_2 is the temperature during precracking in water; T_1 is the subsequent test temperature.

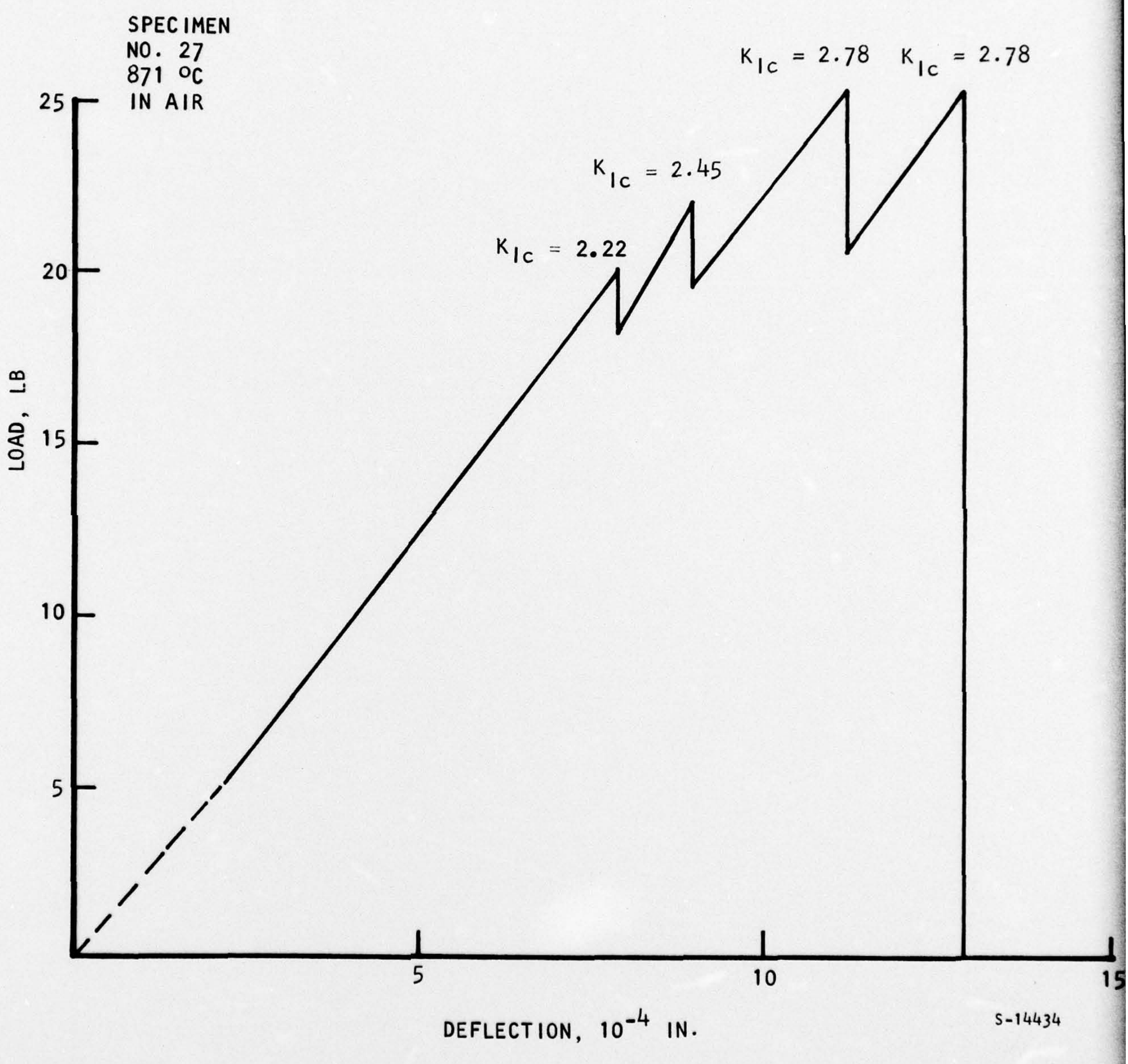

Figure 2-9. Typical Constant Displacement Rate Test Data

There were an insufficient number of high temperature tests to establish the statistical distribution of K_{Ic} values; however, some general observations can be made concerning the data. For Super KT at 871°C in air, K_{Ic} is lower than the measured values in water at room temperature. Between 871°C and 1316°C K_{Ic} increases with increasing temperature. More testing would be required to establish the statistical distribution of the high temperature K_{Ic} values.

2.3.2 Constant Deflection Rate Tests

Investigators have found that the following relationship exists for glass and other brittle materials:

$$Y = P\,(C + Ba)$$

where
- Y = deflection
- P = load
- C = an initial constant
- B = a proportional constant
- a = crack length

Dividing both sides of the equation by P and differentiating both sides with respect to time results in

$$\frac{dy/dt}{P} = B\frac{da}{dt}, \text{ or } \left(\frac{\dot{Y}}{P}\right) = B\dot{a}$$

This formula shows the relationship between deflection rate, $\dot{Y}$, and slow crack growth rate, $\dot{a}$. In order to evaluate the proportional constant B it is necessary to establish load versus deflection curves at a deflection rate which is sufficiently slow to allow the slow crack growth rate to show up as a change of slope or a flattening of the load-deflection curve at the higher deflections. A material with no slow crack growth or a deflection rate which is too fast will result in the failure of the test specimen with no noticeable flattening of the load-deflection curve.

The constant deflection rate tests performed on the specimens did not result in any load-deflection curves with flattening. A typical plot is shown in Figure 2-9. These results indicate that either the deflection rate (1.8 μm/minute) used in the test was too high or that the materials did not have any noticeable slow crack growth.

When the constant deflection rate tests failed to produce any indication of slow crack growth on Super KT specimens, it was decided to conduct some additional tests on glass specimens. The purpose of the testing with the glass specimens was to see if the test procedure used with the ceramic specimens would yield values of slow crack growth for glass that would compare favorably with published values.

Three glass specimens were prepared and inserted in the test fixture with the groove and support assembly (See Figure 2-4) upward so that water would be retained during the test. The test results were similar to those for the Super KT specimens in that no flattening of the load-deflection curves was noticed prior to failure. These results contradict published data for glass where definite flattening of the load-deflection curve occurred before failure. The load cell used for the glass tests was the same one used for the Super KT specimens and has a 100 pound load range. The ability of this load cell to give accurate feedback information for deflection rate control on the glass specimens is not good because the failing load for these specimens was in the order of 2 pounds.

Because of the questionable accuracy of the feedback information from the load cell, the tests on the glass specimens neither proved nor disproved the suitability of the 1.8 μm/minute deflection rate for testing ceramic materials. Further testing with a more sensitive load cell is planned.

2.3.3 Constant Load Tests

When the constant displacement rate tests failed to find any indication of slow crack growth in Super KT, it was decided to conduct a constant load test at 1316°C. One specimen was loaded at 1316°C to approximately 80% of the load found to induce the extension of the precrack on specimens used in the constant load rate tests. The load was held constant for 10 hours and the load and deflection values were monitored and recorded at intervals during the test. The test data is shown in Figure 2-10. No change in crack length could be detected following the test.

The test appears to indicate that there is no slow crack growth for Super KT at 1316°C. One test is not sufficient to prove or disprove the existence of slow crack growth in Super KT material at 1316°C. More constant load testing at 1316°C, and at other elevated temperatures, would be required to characterize the high temperature slow crack growth rates for Super KT material.

2.3.4 Cyclic Crack Growth Tests

Eleven Super KT specimens were selected for cyclic crack growth rate testing. Two specimens were tested at each of the two test temperatures, 871°C and 1093°C, and seven at 1316°C. The applied loading was undirectional (not reversed) and was cycled above and below a mean value. The load range selected varied from a low of approximately 40% to a high of approximately 80% of the load required to extend the precrack on specimens tested in the constant load rate series. The rate of cycling varied between 0.1 Hz and 11 Hz with the majority of the specimens being cycled at 2.78 Hz. The testing continued until the specimen failed or until approximately 10,000 cycles were accumulated. One test at 1316°C was continued until 40,000 cycles were accumulated. The load and deflection excursions were recorded continuously throughout the short duration tests and were recorded at approximately 1000 cycle intervals for the longer duration tests. The results of these tests are summarized in Table 2-4.

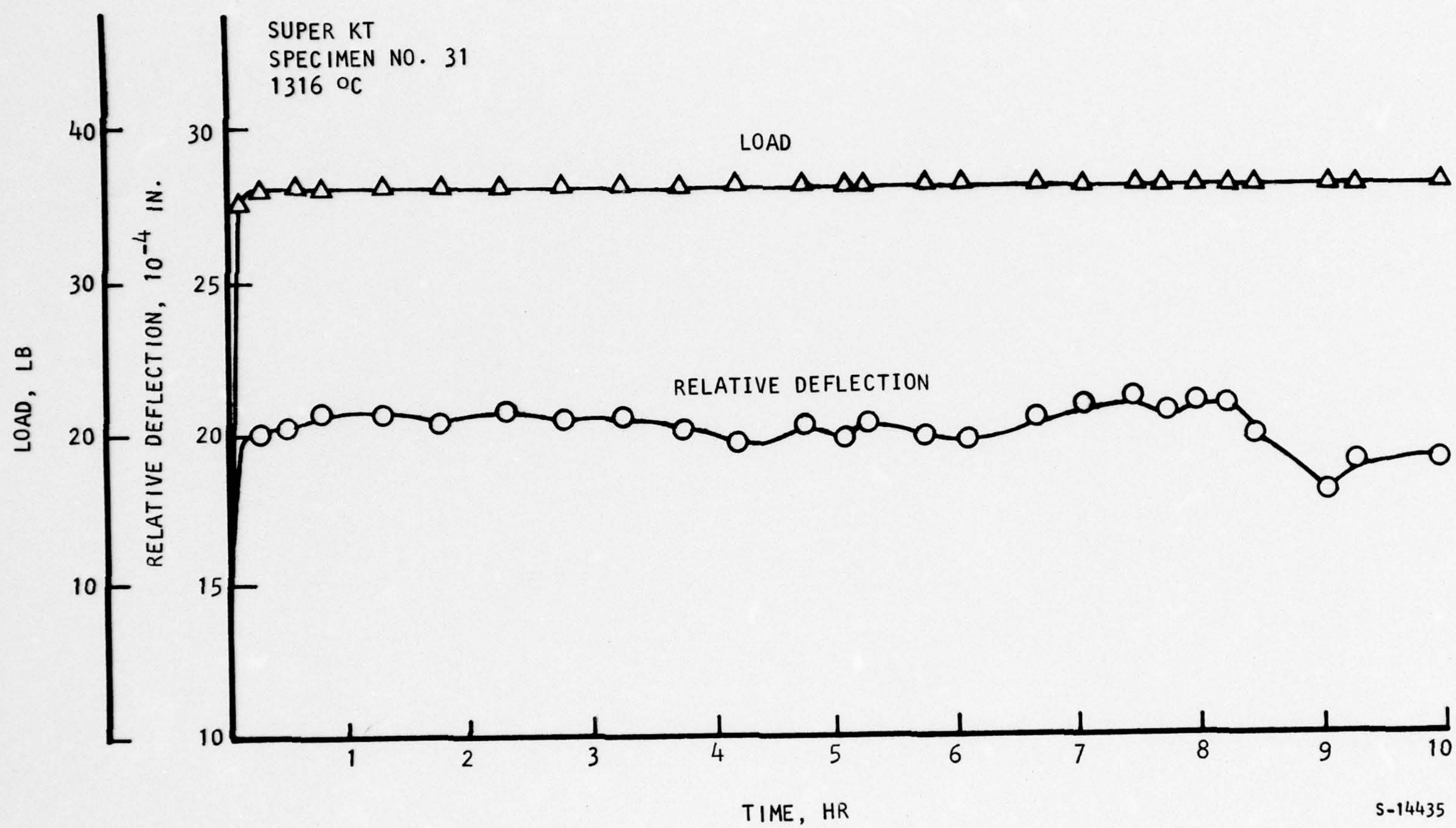

Figure 2-10. Constant Load Test Data

TABLE 2-4

SUMMARY OF CYCLIC CRACK GROWTH DATA

Specimen No.	Test Temp. (°C)	Crack Length, in			Test Cycles	Cycle Rate (Hz)	da/dn (μm/cycle)	Applied Load, Lbs.				ΔK_I ($MNm^{-3/2}$)
		Initial a_o	Final a_f	Δa				Min	Max	Mean	ΔP	
29	871	1.50	1.52	0.02	9,870	1-3	0.05	9.0	19.0	14.0	10.0	2.13
29	1316	1.52	Failed on Loading			–	—	20.0	36.0	28.0	16.0	4.26
31	871	1.75	1.83	0.08	10,000	2.78	0.20	8.5	18.0	12.8	9.5	1.95
32	1093	1.15	1.16	0.01	10,000	2.78	0.03	21.0	36.5	28.3	14.5	4.31
32	1316	1.16	Failed		270	2.78	—	20.0	36.0	28.0	16.0	4.26
33	1093	1.14	Failed		330	2.78	—	16.0	18.0	17.0	2.0	2.59
36	1316	0.98	Failed		190	2.78	—	20.0	36.0	28.0	16.0	4.30
39	1316	1.031	Failed		156	0.1	—	16.0	32.0	24.0	16.0	3.65
40	1316	1.484	1.484	0	360	0.1	0	16.0	32.0	24.0	16.0	3.65
41	1316	0.617	0.937	0.32	4×10^4	11	0.2	12.0	28.0	20.0	16.0	3.00
42	1316	0.907	1.539	0.632	100	0.1	—	16.0	32.0	24.0	16.0	3.65

Two of the seven specimens which were tested at 1316°C, specimens 29 and 32, had been previously subjected to approximately 10,000 cycles at 871°C. Specimen 29 failed on application of the load at 1316°C and specimen 32 failed after 270 cycles. Two other specimens, numbers 36 and 39, which had not been subjected to prior testing also failed after a small number of cycles, 190 cycles and 156 cycles respectively. One specimen, number 41, was cycled at a mean load of 20 pounds at 1316°C and withstood 40,000 cycles without failure. The mean loads for the other specimens tested at 1316°C were 24 and 28 pounds.

The small number of cyclic crack growth rate tests performed do not form a sufficient statistical base for establishing da/dn values for Super KT but they do verify the test procedure used and give a "ballpark" feel for the da/dn values to be anticipated. Much more of this type of testing will be required to establish da/dn ranges for this material. The relatively large percentage of specimens which failed at a low number of cycles at 1316°C would seem to indicate that Super KT would not be a viable candidate for use in high temperature applications which are subjected to cyclic loading.

SECTION 3

SUMMARY AND DISCUSSION

The stress intensity factor, K_{Ic}, for Super KT material tends to first decrease from its value at room temperature (in water) with increasing environmental temperature and then increase with increasing temperature (in air). At room temperature, in water, the average K_{Ic} value for Super KT is approximately 3.5 $MNm^{-3/2}$ while at 1316°C in air the average K_{Ic} values have increased to approximately 5.3 $MNm^{-3/2}$. Based on the small amount of high temperature testing, Super KT would appear to have a slightly higher K_{Ic} value at elevated temperatures than KT and NC-430(2). More elevated temperature testing will be required to verify these trends.

The constant deflection rate tests failed to produce the anticipated flattening of the load versus deflection curves with increasing deflection. Failure to establish the load plateau during constant deflection rate testing can be caused by a rate which is too high to allow the plateau to develop or by an absence of slow crack growth in the material being tested. The deflection rate used in the testing was 1.8 μm/min. If the crack growth rate induced by the test deflection rate is higher than the normal specimen crack growth rate, the specimen will simply crack along its entire length without exhibiting the desired flattening of theload vs. deflection curve at the higher deflection. To obtain the desired load vs. deflection curves, the constant deflection rate must be reduced to a level which is of the same order of magnitude as that of the slow crack growth rate of the material being tested. For materials with low slow crack growth rates, the required test time could be cost-prohibitive.

When the Super KT specimens failed to show the anticipated flattening of the load versus deflection curve it was decided to conduct similar tests on glass specimens in an attempt to duplicate published load versus deflection data. These tests also failed to produce the load plateau found in published data. The results of the glass tests would seem to indicate that the 1.8 μm/min deflection rate is too high to allow the load-deflection curve to develop the plateau. The glass test results are questionable due to the fact that the load cell used in these tests was not sufficiently sensitive to give accurate feedback information for proper deflection rate control. More testing with a more sensitive load cell will be required to establish the ability of the 1.8 μm/min deflection rate to produce acceptable results.

An examination of the test procedure used in the constant deflection rate testing indicated other possible improvements for future testing. The use of wider and thinner specimens would provide a larger deflection for a given stress value. Small errors in measurement would be a much smaller percentage of the larger deflection band. The reduction in specimen thickness is much more effective in increasing deflection than an increase in specimen width. Another possible improvement in the measurement of deflections would be to measure the relative displacement between the specimen and its holding fixture. The present method of measuring specimen deflection is by measuring the movement of the cross head of the testing machine. This includes the load cell, the push rods and holders, and the test fixture and the test specimen.

One Super KT specimen was tested at 1316°C at a constant load of approximately 80% of the precrack load. No slow crack growth was found in the tested specimen.

The absence of slow static crack growth in Super KT is consistent with the absence of the expected load plateau during constant velocity testing, and with previous findings for non-siliconized sintered SiC containing boron[3]. However, discontinuous "fast" crack growth could well have occurred as evidenced by several abrupt drops in load, as well as by some premature failures during loading.

More constant load testing must be conducted at elevated temperatures to establish whether slow crack growth exists for Super KT and to determine the statistical distribution of this growth if it does exist.

The cyclic crack growth rate is affected by many more factors than the static crack growth rate. Evans and Linzer[4] have found that the cyclic crack growth rate is a function of temperature, frequency, mean stress intensity factor, and load amplitude. The cyclic crack growth rate testing accomplished to date on the Super KT specimens have provided two data points at 871, 1093 and 1316°C at a cyclic frequency of 2.78 Hz and two additional points at 1316°F, one at a cyclic frequency of 0.1 Hz and one at a cyclic frequency of 11 Hz. Many more data points are required to characterize the cyclic crack growth rate with respect to the factors mentioned above. Evans and Linzer[4] also pointed out that, where the cyclic growth rate data does not depend on cycling frequency, the cyclic and quasi-static slow crack growth mechanisms are equivalent, i.e., the cyclic growth data can be derived from the slow crack growth data [5]. The transition temperature at which the cyclic and quasi-static slow crack growth mechanisms start to differ has not been determined.

Insufficient data was obtained to permit meaningful proof test diagrams and applications studies to be completed.

SECTION 4

FUTURE WORK

Because of its higher operating temperature potential, non-siliconized sintered SiC is more attractive for heat exchangers than siliconized silicon carbide grades (containing free silicon). The recent developments in producing this type of SiC have made its future availability in fabricated shapes appear economically feasible. Accordingly, the attention of this program for next year will be directed primarily to the crack growth and fracture toughness of non-siliconized sintered SiC, using the most effective test techniques available.

In addition, testing of Super KT will be continued, to more accurately characterize its static and cyclic load response so that a meaningful design application study can be carried out. Tests on glass specimens will also continued to verify existing data forms, using a low-range load cell.

SECTION 5

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